ASSEMBLAGES OF MIOSPORES FROM SOME UPPER CARBONIFEROUS COALS AND THEIR ASSOCIATED SEDIMENTS IN THE YORKSHIRE COALFIELD

by A. E. MARSHALL and A. H. V. SMITH

Abstract. An investigation has been made of the miospore assemblages in the coals at the bottom and top of certain Yorkshire seams and in the adjacent seat-earths and roof measures. The assemblages from the sediments are similar and are often richer in numbers of species than those from the adjacent coals. The spores provide no evidence for the existence on the seat-earths of a distinctive type of vegetation differing significantly in composition from that which formed the initial peat layer. Several spore genera do, however, show greater frequency of occurrence in the sediments than in the coals. The investigation suggests the value of seat-earths for the solution of correlation problems when the associated coal is lacking. Four new miospore species from the sediments are described, also remains of the algal genus *Botryococcus*. The miospore species are *Leiotriletes turgidus*, *Punctatisporites arenosus*, *Convolutispora tumulosa*, and *Savitrisporites concavus*.

Many workers have studied the spores in coal seams and in recent years assemblages have been described from other rocks. There have been few comparative studies of the spores in coal seams and their associated sediments. Hoffmeister, Staplin, and Malloy (1955), Neves (1958), and Staplin (1960) examined short sequences of sediments from single geological horizons.

A more extensive investigation was carried out by Neves (1961) on a series of unassociated sediments and coals of Namurian age from central England. This work confirmed the earlier observations that whereas some species transgress 'facies boundaries' and are present in coal, non-marine shales, and marine shales, others were recorded only from a particular type of rock.

Of particular relevance to the present investigation are the results of Sullivan (1962) who described spore assemblages from coals and shales collected from forty-five horizons within the Coal Measures sequence in South Wales. Sampling through any one cyclothem was discontinuous although the total number of samples included at least one example from each lithological unit within a cyclothem. Preparations from the seat-earths and the sandstones yielded few or no spores. The assemblages from the basal part of the roof shales were comparable both in composition and proportion of species with those from the underlying coal seams. This also applied to some of the shales well above the coals. The differences between the composition of these assemblages are of the same order as those between different coal types from the same seam (Smith 1957, 1962).

No systematic attempt has been made to compare assemblages in the seat-earths and roof measures with those from the adjacent portions of coal seams. Little is therefore known of the precise changes which took place in the vegetation at the beginning and end of peat formation.

Considerable practical advantages to coalfield geology will result from a study of the spores in clastic sediments. Sullivan (1962) has shown that many of the spores which

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have been used for zoning the coal-bearing strata of Great Britain (Butterworth and Millott 1960) have similar stratigraphic ranges in the sediments and the coals. In areas where the rank of the coal prohibits the isolation of the spores from the coal, seams can still be placed in their approximate stratigraphic position on the basis of the spores in the associated sediments as suggested by Sullivan.

Seat-earths are worth investigating for their value as a means of correlating horizons where expected coal seams appear to be lacking. In these instances the seat-earths, which are often of considerable lateral extent, may provide the only reliable basis for correlation.

For these reasons a preliminary investigation was made of the assemblages of small spores (miospores) in the coals adjacent to the roofs and floors and in a limited thickness of these immediate roofs and floors from some of the more important seams from the Lower and Middle Coal Measures of the Yorkshire coalfield (Westphalian A, B, and lower C). These seams, the sampling localities, and brief descriptions of samples are given in the Appendix. Ash values are given as a rough guide to the organic content of the samples as well as the colour of each dry powdered rock sample as determined in daylight by reference to the Geological Society of America Rock Color Chart (1951).

Most of the samples were collected specially from underground workings for the present investigation. This imposed a restriction on the thickness of sample which could be collected from below the coal seam. In order to increase the number of seams examined, use was made of certain subsections collected as part of the routine seam-survey programme of the National Coal Board Coal Survey Laboratory at Sheffield. The thickness of some of these samples is not known. Wherever possible, however, the thickness of coal was restricted to a few inches to avoid obvious changes in petrographic type. The distinction between coal, inferior coal, and coaly shale was made subjectively in the present investigation. In most instances the boundary between the coal and the adjacent sediment was readily apparent but there were cases where the transition was gradual and less easily defined. The Swallow Wood seam was sampled at two localities 5 miles apart to examine the nature of lateral variation in spore content.

TECHNIQUES

The coals in this investigation were macerated with fuming nitric acid (S.G. 1·5). A representative sample of each coal was crushed to just pass a 36 BS sieve (aperture 0·42 mm.) and approximately 0·5 g was treated with acid at room temperature for 16 hours. Experience has shown that this method is less liable to result in chemical attack of the spore exines than that using Schulze reagent and alkali.

The sediments were crushed to pass a 14 BS sieve (aperture 1·20 mm.) and depending on the organic content 1–2 g of the powdered rock were pretreated with 40 per cent. hydrofluoric acid for at least 48 hours in a water bath at 40° C. to remove silicates. The organic residue was then macerated by the so-called dry Schulze method. In practice 0·6 g of crystalline potassium chlorate and 20 ml. of concentrated nitric acid were added to the moist residue after removal of the hydrofluoric acid. The alkali-soluble ulmins were removed from the maceration residue by washing with 5 per cent. potassium hydroxide. Schulze reagent was used on the sediments in preference to fuming nitric acid since the reaction is more easily controlled, an important consideration when the amount of organic material requiring oxidation is variable.

In the case of the roof of the Pot Clay coal, it was found that gentle boiling with 100-volume hydrogen peroxide gave better results than the Schulze method.

The maceration residues were subjected to ultrasonic vibrations in a 80/40-watt transistorized 'Soniclean' with tank-type transducer for periods of time which varied with the individual samples. This treatment cleans and disaggregates the spores when this is necessary, generally facilitating subsequent examination.

Finally, two slides were prepared from the spore residue of each sample, one being an open and the other a covered gelatine mount. A count of 500 spores was then made, based on 250 spores from each slide. Frequencies determined in this manner have increased accuracy (Tomlinson 1957). Both slides were then traversed completely for forms not observed during the initial counting. The open slides in each case provided the spores for single grain mounts.

SYSTEMATIC PALAEONTOLOGY

The terminology employed in the descriptions is that recommended by the nomenclature sub-committee of the International Committee of the Microflora of the Palaeozoic. All type and certain other figured specimens mounted singly in glycerine jelly are referred to by a preparation number. The remaining figured specimens, not so prepared, are referred to by a preparation number followed by the 'east–west' and 'north–south' mechanical stage readings from a Vickers Instruments (Cooke, Troughton, and Simms) biological research microscope. All figured specimens are available for reference at the Coal Survey Laboratory of the National Coal Board, Sheffield.

Anteturma SPORITES H. Potonié 1893
Turma TRILETES (Reinsch) Potonié and Kremp 1954
Subturma AZONOTRILETES Luber 1935
Infraturma LAEVIGATI (Bennie and Kidston) Potonié 1956
Genus LEIOTRILETES (Naumova) Potonié and Kremp 1954

Leiotriletes turgidus sp. nov.

Plate 99, figs. 1–3

Holotype. Plate 99, fig. 1. Preparation T75/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb triangular to roundly triangular, sides concave, straight or convex, apices narrowly to broadly rounded, margin smooth. Laesurae simple, generally accompanied by folds aligned more or less parallel with the rays and giving the appearance of prominent lips; laesurae and folds extend nearly to equator. Exine thick, 5–7 μ, and laevigate; often pyramidally elevated, culminating in vertex. Single distal compression fold often follows margin.

Size (25 specimens). Maximum dimensions from apex to opposite inter-radial margin 59 (77) 104 μ; holotype 82 μ. Treatment, dry Schulze and 5 per cent. KOH.

Description. Shape somewhat variable depending on convexity of inter-radial margins. Combined width of 'lips' 10–17 μ. Continuous marginal fold often present, more or less uniform in width and situated distally from the equator. Presence of fold appears to be related to state of compression of exine; forms with elevated proximal surface appear to lack marginal fold. Exine thickness often visible at spore margin; colour reddish-brown to very dark brown.

Comparison. Leiotriletes ornatus Ishchenko 1956 in Playford 1962, p. 575, is morphologically similar but is smaller, 32 (46) 63 μ, with thinner exine (2–3·5 μ) and narrower lips (each 2·5–4·5 μ wide). Spore type 1 described by Love (1960, p. 122) is considered by Playford to be 'undoubtedly representative' of *L. ornatus*. Spore type 2 (ibid.) is similar in shape and size to *L. turgidus* sp. nov. but 'shows very strong infrastructure'.

Spore type C of Neves (1958, pl. ii, fig. 6) is morphologically very like *L. turgidus* but is circular with very broad lips (14–20 μ wide).

Genus PUNCTATISPORITES (Ibrahim) Potonié and Kremp 1954

Punctatisporites arenosus sp. nov.

Plate 99, figs. 4, 5

Holotype. Plate 99, fig. 4. Preparation T76/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb circular to subcircular, commonly distorted by compression; margin smooth. Laesurae simple, reaching nearly to amb, infrequent. Exine with granulate infrastructure, generally strongly developed and usually with distinct pseudo-rim, 2–7 μ wide. Compression folds characteristic, randomly orientated, frequently long and narrow.

Size (25 specimens). 82 (104) 126 μ; holotype 109 μ. Treatment, dry Schulze and 5 per cent. KOH.

Description. Although a tetrad mark is infrequently seen (*c*. 5 per cent. of spores examined) exine commonly shows a triangular tear which has probably resulted from a rupture along a triradiate line of weakness. Laesurae may be obscured by folds more or less parallel to sutures. Pseudo-rim structureless, with ill-defined inner margin; results from viewing the hyaline substance of the exine wall with its internal structure in strongly compressed material.

Comparison. The size, general absence of tetrad mark, distinct infrastructure and characteristic form of the folding are all features which serve to distinguish this species from all other previously described forms of the genus *Punctatisporites*.

Infraturma MURORNATI Potonié and Kremp 1954

Genus CONVOLUTISPORA Hoffmeister, Staplin, and Malloy 1955

Convolutispora tumulosa sp. nov.

Plate 99, figs. 6–8

Holotype. Plate 99, fig. 6. Preparation T77/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb circular to subcircular, margin more or less undulate to smooth. Laesurae simple or with thickenings parallel to the commissure, often indistinct or not seen, straight or sinuous, two-thirds radius to margin. Proximal and distal ornament of continuous anastomosing ridges, rounded conical to flat-topped in optical section, up to 4 μ in height and 4–10 μ in basal width (measured at margin), maximum width at their confluence, enclosing irregularly shaped lacunae with maximum diameter 2–10 μ. Ornament, particularly in high focus, gives a reticulate pattern; inner surface of exine shows a distinct reticulum. Number of ridges projecting at margin 20–25. One or two random folds may be present. Exine thin in lacunae.

Size (25 specimens). 54 (64) 77 μ: holotype 68 μ. Treatment, dry Schulze and 5 per cent. KOH.

Description. Shape variable, depending on compression, probably originally spherical since there is no preferred orientation. Margin generally, at least in part, strongly undulose. Sides of ridges parallel or converging, usually towards apex. Distinctness of outer reticulum variable due to fluctuating height and width of ridges; generally visible with careful focusing. Inner reticulum positive, distinct and regular; probably a compression feature of the outer reticulum.

Comparison. In *Convolutispora mellita* Hoffmeister, Staplin, and Malloy 1955 (size 60–85 μ) the ridges are not so broad (2·8–5·6 μ) and reticulation is less marked. Specimens of *C. mellita* from the type locality were examined by the authors. *Convolutispora* sp. A. Neves 1961 is larger (122 μ) and has somewhat broader sculptural elements (6–10 μ wide). *Reticulatisporites textilis* Balme and Hassel (1962) is also larger (size 89 (106) 135 μ), has smoother margin, and a more distinct reticulum.

Palaeobotanical affinites. Radforth (1939, pl. i, figs. 2, 6, 7) and W. and R. Remy (1957, pl. 3, figs. 5–7) have figured spores of closely comparable size, 52 (61) 70 μ (Radforth 1939), and morphology to those of *Convolutispora tumulosa* sp. nov. from the schizaeaceous fern *Senftenbergia pennaeformis* Brongniart. Butterworth and Williams (1958) noticed the close similarity between the spores of *S. sturi* Sterzel and the dispersed spore *Savitrisporites* (*Callisporites*) *nux* (Butterworth and Williams) Sullivan 1964. It is of

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EXPLANATION OF PLATE 99

All figures ×500 except where stated. All miospores photographed are from seat-earth of Swallow Wood Seam, Elsecar Main Colliery, Yorkshire.

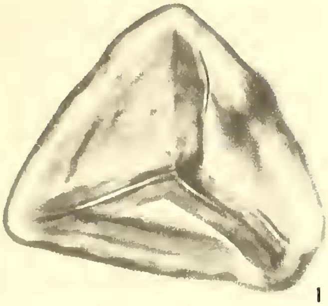
Figs. 1–3. *Leiotriletes turgidus* sp. nov. 1, Holotype; proximal surface. 2, 3, Proximal view, medium focus; preparations T75/2 and T75/3.

Figs. 4, 5. *Punctatisporites arenosus* sp. nov. 4, Holotype, ? proximal view, low focus. 5, Proximal view, medium focus; preparation T76/2.

Figs. 6–8. *Convolutispora tumulosa* sp. nov. 6, Holotype, medium focus. 7, Proximal surface; preparation T77/2. 8, Low focus showing reticulate inner surface of exine through tear; preparation T77/3.

Figs. 9–12. *Savitrisporites concavus* sp. nov. 9, Holotype, proximal surface. 10, Distal surface; preparation T78/2, 22·0 78·0. 11, Proximal surface; preparation T78/2, 18·5 76·5. 12, Proximal surface; preparation T78/3, 8·1 76·8.

Figs. 13–16. *Savitrisporites nux* (Butterworth and Williams) Sullivan. 13, Distal surface; preparation T78/2, 30·5 65·0. 14, Distal surface; preparation T55/2 (mounted between two cover glasses) ring number 4. 15, 16, Preparation T55/2, ring number 2, ×1000: 15, Proximal surface; 16, Distal surface (preparation photographed from reverse side).



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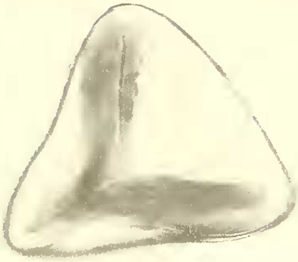

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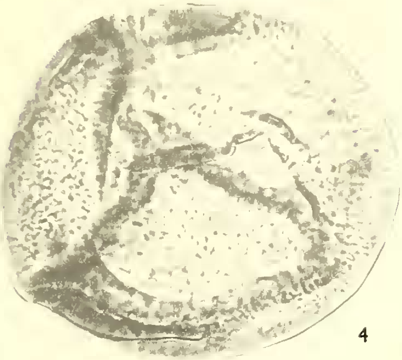

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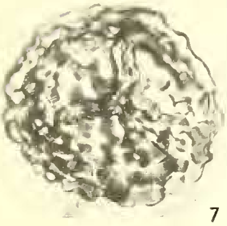

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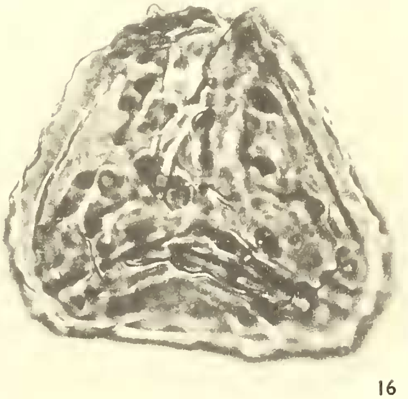

16

MARSHALL and SMITH, Upper Carboniferous miospores

interest that both species of dispersed spores are well represented in the assemblages from the seat-earth of the Swallow Wood seam at Elsecar Main Colliery.

Turma ZONALES (Bennie and Kidston) Potonié 1956
Subturma ZONOTRILETES Waltz 1955
Infraturma CINGULATI Potonié and Klaus 1954
Genus SAVITRISPORITES Bharadwaj 1955

Savitrisporites concavus sp. nov.

Plate 99, figs. 9–12

Holotype. Plate 99, fig. 9. Preparation T78/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb triangular, sides straight to strongly concave, margin more or less crenulate to smooth, apices pointed to narrowly rounded. Laesurae simple, straight, reaching inner margin of cingulum, suture often open. Proximal ornament, if present, of ridges bordering laesurae; distal ornament, if present, of irregular thickenings. Apical swellings often developed. Cingulum width often variable on any one specimen.

Size (25 specimens). Maximum dimension from apex to opposite inter-radial margin 29 (34) 43 μ; holotype 43 μ. Treatment, dry Schulze and 5 per cent. KOH.

Description. Laesurae often appear to have thickened lips owing to a broad, flat-topped ridge bordering each ray and occupying most of central area. Distal ornament, when developed, usually prominent (height 2–4 μ) mainly around distal pole and radiating towards each apex. A pair of apical swellings may be developed from ornament on either surface. Cingulum often widest in radial positions and frequently irregular in profile, possibly as result of corrosion.

Comparison. Savitrisporites (*Callisporites*) *nux* (Butterworth and Williams) Sullivan is larger, 30 (47) 60 μ (in Sullivan), its shape is typically convex and it possesses regularly disposed distal ornament. Specimens of *S. nux* are illustrated in Plate 99, figs. 13–16 of this paper for comparison. In the type material a small number of specimens have been observed with features intermediate between *S. concavus* and *S. nux*. *S. asperatus* Sullivan 1964 is of comparable size, but its sides are less concave, the inner margin or the cingulum is less well defined, the irregular distal thickenings cover the whole distal surface, apical thickenings are more prominent and the exine is thicker. *S. triangulus* Bharadwaj 1955 is larger (53–65 μ), has straight sides, and possesses a heavier distal ornament.

ALGAE-XANTHOPHYCEAE
Genus BOTRYOCOCCUS

Plate 100, figs. 1–4

Discussion. The immediate roof of the Shafton seam as collected from Dearne Valley Colliery Drift consists of 5 in. of coaly mudstone. The spore residue obtained by macerating this material contained many branched, hollow structures which, on both size and morphology, may be grouped with the polymorphic algal species *Botryococcus braunii* Kützing 1849. *Botryococcus* has a stratigraphic range from at least Lower Carboniferous to Recent (Traverse 1955). The forms found in the present work compare closely with the descriptions and illustrations of Blackburn and Temperley (1936) who dealt with both fossil and modern forms of *Botryococcus*.

The Shafton specimens bear closest resemblance to the branched *Pila* colonies shown in Temperley's pl. i, figs. 9, 10, although they are usually more fragmentary. The hollow nature of the branches with a distinct tendency to be incurved at the tips is evident in Plate 100, figs. 2, 3. On some of the axes a ladder-like pitting is visible, Plate 100, fig. 4, and this may be similar in origin to the scalariform structure observed by Blackburn, which she interpreted as the product of 'the separation of the basal portions of the cups and their lamellae' (1936, p. 844). Scattered circular granules may also occur on the branches. Only the cuticular thimbles of *Botryococcus* appear to be preserved in the material examined, the enclosed cells and outer waxy cups being absent. The radial groups of cells which form spherical colonies are commonly preserved but are now compressed to disc-like aggregates.

Thin sections were prepared of the shale from which the algae had been isolated. These sections contained scattered fragments of the alga with the same form as those obtained by maceration. It was therefore evident that no structural changes had taken place during the maceration process.

Further thin sections of the immediate roof of the Shafton seam, from several localities in the Yorkshire coalfield, proved to contain *Botryococcus* of the form illustrated. The persistence and abundance of *Botryococcus* in the Shafton roof may well prove to be a reliable marker for this horizon. It would appear that the conditions suitable for the growth of *Botryococcus* were widespread in Yorkshire immediately above the Shafton seam.

Fragments of the alga have also been found sporadically in separations from seat-earth, roof, and coal samples from the Flockton, Swallow Wood, and Barnsley seams examined during the course of this work.

Records of the occurrence of *Botryococcus* in primarily inorganic sediments of Coal Measures age in the British coalfields are rare. Neves has found *Botryococcus* to be widespread at two principal horizons in the non-marine shales of the southern Pennines, namely the *Carbonicola exporecta* horizon (1961, p. 277) and the roof of the Pot Clay coal (pers. comm.).

MIOSPORE ASSEMBLAGES IN COALS AND THEIR ASSOCIATED SEDIMENTS

Adequate numbers of miospores were isolated from all the samples so that counting 250 specimens per slide presented no difficulty even with separations from sediments.

EXPLANATION OF PLATE 100

Figs. 1–4. *Botryococcus* isolated from roof measures of Shafton seam. 1, Portion of colony. 2, 3, Fragments of colony with hollow terminal cups; preparation T79/2, 15·1 87·0 and 8·9 72·3. 4, Axes of portion of colony showing characteristic markings; preparation T79/2, 35·0 86·5. All figures ×500.


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MARSHALL and SMITH, Upper Carboniferous *Botryococcus*
HUNTER and LANGSTON, Odontoma in mammoth

In general, over the thickness sampled, coaly rocks yielded larger numbers of spores but fewer species than the samples containing less organic material. Therefore the number of species generally tends to increase with distance from the coal. However, the numbers of species in the coals and in the associated rocks of any one seam may differ considerably from the numbers in any other seam (Table 1).

TABLE 1. Number of species per 500 spores in coal and associated sediments.

Seam	Seat-earth				Bottom of Seam		Top of Seam	Roof Measures				
Shafton			40	26	22		54	34	56	43	52*	42
Beamshaw				28	30							
Barnsley	27	28	27	34	24		32	38				
Swallow Wood			54	46	43		40	49				
Swallow Wood			58	49	40		42	41				
Flockton Thick				54	28		33	44				
Silkstone				23	22							
Top Beeston				15	15							
Pot Clay				41		22		19				

Inferior coal*

The true diversity of the microflora is not always apparent from a count of 500 specimens when one species is overwhelmingly dominant in the assemblage. This is true of the seat-earth of the Beeston seam and the roof of the Pot Clay seam from which a large number of species were recorded after examination of the entire slides prepared from these samples.

Table 2 lists the genera and the number of their species recorded from the samples. The occurrence of the genera in seat-earths and roof measures and the number of species in samples of each type are also recorded.

Few genera are recorded exclusively from one type of sample. Genera with species whose abundance exceeds 2 per cent. in any sample are indicated in the table. Very few of such genera consistently attain this level of abundance.

Table 3 shows the abundance of *Lycospora* spp. in the sediments and coals. With four exceptions, two from the Shafton seam and two from the Swallow Wood seam, this genus dominates all the assemblages, exceeding 50 per cent. in most instances and sometimes 80 per cent. of the total spores counted.

The frequencies of the other relatively abundant genera or species in the coals and sediments are shown graphically in text-figs. 1, 2, and 3. Several genera such as *Calamo-*

TABLE 2. Occurrence of genera and representation of species in coals and associated sediments.

Genus	Total number of species	*Number of samples containing genus*				*Number of species in samples*			
		Sediments		*Coals*		*Sediments*		*Coals*	
		Seat-earth (total samples 8)	*Roof (total samples 5)*	*Bottom (total samples 8)*	*Top (total samples 5)*	*Seat-earth*	*Roof*	*Bottom*	*Top*
Reticulatasporites (Ibrahim) Pot. and Kr. 1954*	1	2	3	4	2	1	1	1	1
Granasporites Alpern 1959*	1	6	4	3	3	1	1	1	1
Leiotriletes (Naumova) Pot. and Kr. 1954*	4	8	3	8	5	4	4	4	4
Ahrensisporites Pot. and Kr. 1954	1	2	2	1	1	1	1	1	1
Punctatisporities (Ibrahim) Pot. and Kr. 1954	3	6	2	1	1	3	1	2	1
Calamospora Schopf, W. and B. 1944*	6	8	5	5	5	6	5	5	5
Granulatisporites (Ibrahim) Pot. and Kr. 1954	6	8	4	7	5	6	5	5	5
Cyclogranisporites Pot. and Kr. 1954*	4	5	4	7	4	4	4	4	3
Verrucosisporites (Ibrahim) Pot. and Kr. 1954	3	2	2	2	–	3	1	2	–
Lophotriletes (Naumova) Pot. and Kr. 1954*	6	7	4	7	4	6	4	4	4
Anapiculatisporites Pot. and Kr. 1954	2	2	2	4	2	2	2	2	2
Apiculatisporis Pot. and Kr. 1956*	7	6	5	6	4	6	5	4	6
Planisporites (Knox) Pot. and Kr. 1954	1	5	5	4	3	1	1	1	1
Crassispora Bharadwaj 1954*	1	8	5	8	5	1	1	1	1
Pustulatisporites Pot. and Kr. 1954	1	4	2	3	2	1	1	1	1
Acanthotriletes (Naumova) Pot. and Kr. 1954	4	2	3	1	2	3	3	1	3
Ibrahimispores Artuz 1957	1	–	1	–	–	–	1	–	–
Raistrickia (Schopf, W. and B.) Pot. and Kr. 1954*	4	8	5	8	5	4	4	3	4
Foveolatisporites Bharadwaj 1955	1	–	1	–	1	–	1	–	1
Dictyotriletes (Naumova) Pot. and Kr. 1954*	4	6	4	4	3	4	3	3	3
Novisporites Bharadwaj 1957*	1	1	1	1	1	1	1	1	1
Reticulatisporites (Ibrahim) Pot. and Kr. 1954	4	2	2	1	1	3	3	1	2
Knoxisporites Pot. and Kr. 1954	2	3	2	2	1	2	2	2	1
Camptotriletes Naumova 1937	2	4	2	4	1	2	2	2	1
Convolutispora Hoffmeister, S. and M. 1955*	1	2	–	1	–	1	–	1	–
Vestispora Wilson and Hoffmeister 1956	3	5	5	5	3	2	3	2	2
Triquitrites (Wilson and Coe) Pot. and Kr. 1954*	3	2	1	2	1	2	3	2	2
Anulatisporites (Loose) Pot. and Kr. 1954*	1	3	4	1	2	1	1	1	1
Densosporites (Berry) Pot. and Kr. 1954*	3	6	3	5	2	3	1	2	2
Cingulizonates Dybova and J. 1957*	3	4	5	2	2	2	3	2	2
Lycospora (Schopf, W. and B.) Pot. and Kr. 1954*	4	8	5	8	5	4	4	4	4
Savitrisporites Bharadwaj 1955*	3	6	4	4	2	3	2	1	1
Cristatisporites Pot. and Kr. 1954	3	2	3	2	2	2	3	1	2
Cirratriradites Wilson and Coe 1940*	4	5	5	3	3	4	2	2	2
Reinschospora Schopf, W. and B. 1944	1	2	1	–	–	1	1	–	–
Laevigatosporites Ibrahim 1933*	2	6	4	7	4	2	2	2	1
Punctatosporites Ibrahim 1933*	2	6	4	7	4	1	2	1	2
Auroraspora Hoffmeister, S. and M. 1955	1	1	1	–	–	1	1	–	–
Endosporites Wilson and Coe 1940*	2	4	4	4	4	2	2	2	2
Florinites Schopf, W. and B. 1944	6	8	5	8	5	6	6	5	5
Alatisporites Ibrahim 1933	1	1	2	3	–	1	1	1	–
Schopfipollenites Pot. and Kr. 1954	1	3	2	2	–	1	1	1	–

* Genera with species whose abundance is greater than 2 per cent. in at least one sample.

spora Schopf, Wilson, and Bentall, *Densosporites* (Berry) Potonié and Kremp, and *Florinites* Schopf, Wilson, and Bentall often show higher values in the seat-earths and sometimes in the roof measures than in the associated coals.

It is interesting that the assemblages from the seat-earth of the Swallow Wood seam in which *Lycospora* spp. are less abundant contain numbers of spores whose palaeobotanical affinities are with the schizaeaceous fern genus *Senftenbergia*. Thus *Convolutispora tumulosa* sp. nov. *Raistrickia saetosa* (Loose) Schopf, Wilson, and Bentall and *Savitrisporites nux* (Butterworth and Williams) Sullivan account for 20 per cent. of the assemblages from seat-earth B at Elsecar Main Colliery and from 5 to 7 per cent. of the assemblages from the other samples of seat-earth from this seam.

TABLE 3. Abundance of *Lycospora* spp. in coals and associated sediments.

Seam	Seat-earth				Bottom of Seam		Top of Seam	Roof Measures				
	percentage abundance							percentage abundance				
Shafton			69	62	85		8	30	11	37	18*	40
Beamshaw				83	38							
Barnsley	85	87	83	78	86		71	58				
Swallow Wood			37	29	38		44	59				
Swallow Wood			15	47	27		32	60				
Flockton Thick				47	69		54	44				
Silkstone				91	95							
Top Beeston				95	95							
Pot Clay				67	63			78				

Inferior coal*

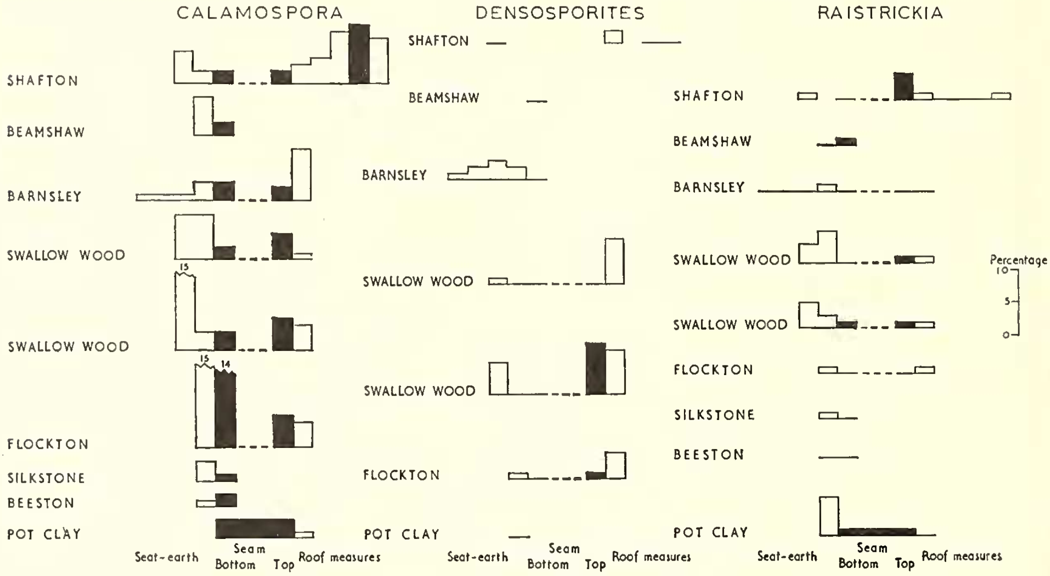
ECOLOGICAL SIGNIFICANCE OF RESULTS

Seat-earths and associated coals

Existing theories concerning the formation of seat-earths are based on general geological considerations and particularly on the mineralogical evidence. These theories are considered by Beerbower (1961) and Huddle and Patterson (1961), who favour the view that seat-earths were probably waterlogged prior to diagenesis and do not represent terrestrial soils subject to long periods of subaerial weathering. The presence of spores in seat-earths does not support either view, since spores can be preserved in waterlogged and drained acid soils in temperate or tropical latitudes for thousands of years (Dimbleby 1961), and probably indefinitely if such soils were subsequently covered by peat.

It may be possible to deduce something of the environment of seat-earth formation from the spore data if it is possible to discriminate between the sources which probably contributed to the spore assemblages.

The spores which were distributed along with the mineral sediment before the establishment of vegetation on these deposits have an allochthonous origin. As plants began to colonize these sediments the autochthonous element would become progressively more important. The extent to which this latter element is represented in the assemblages would be related to the amount of mineral sediment that continued to be deposited after plants began to grow. It is likely that the proportion of the assemblage attributable to the wind-borne element would also have become much smaller once plant cover had developed, to judge by the small extent to which present-day surface samples are influenced by nearby vegetation types. For discussion of the literature on this aspect reference should be made to Dimbleby (1961).

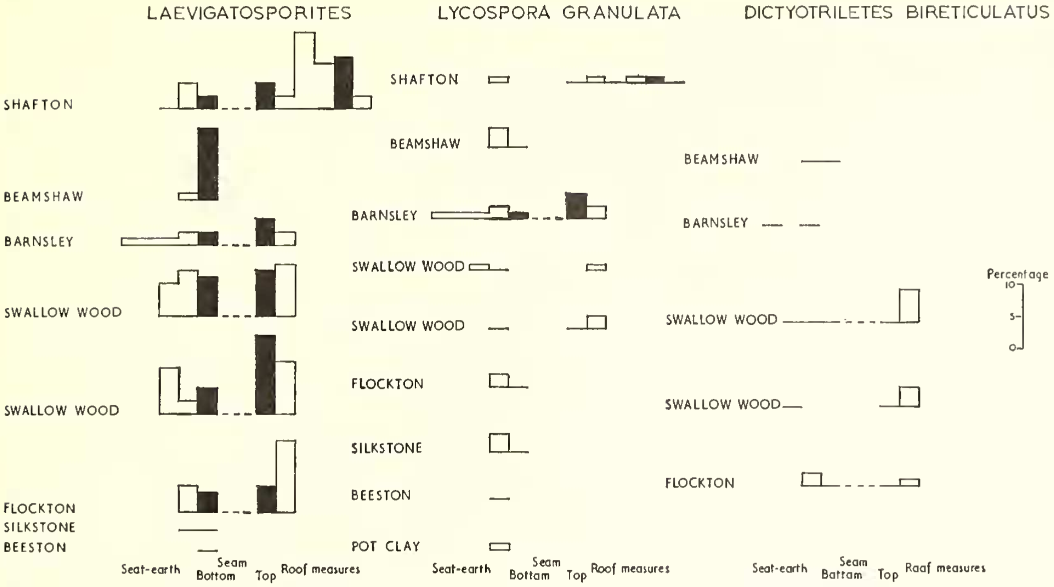


TEXT-FIG. 1. Abundance of certain genera in seat-earths, roof measures, and associated coals of some Yorkshire seams.

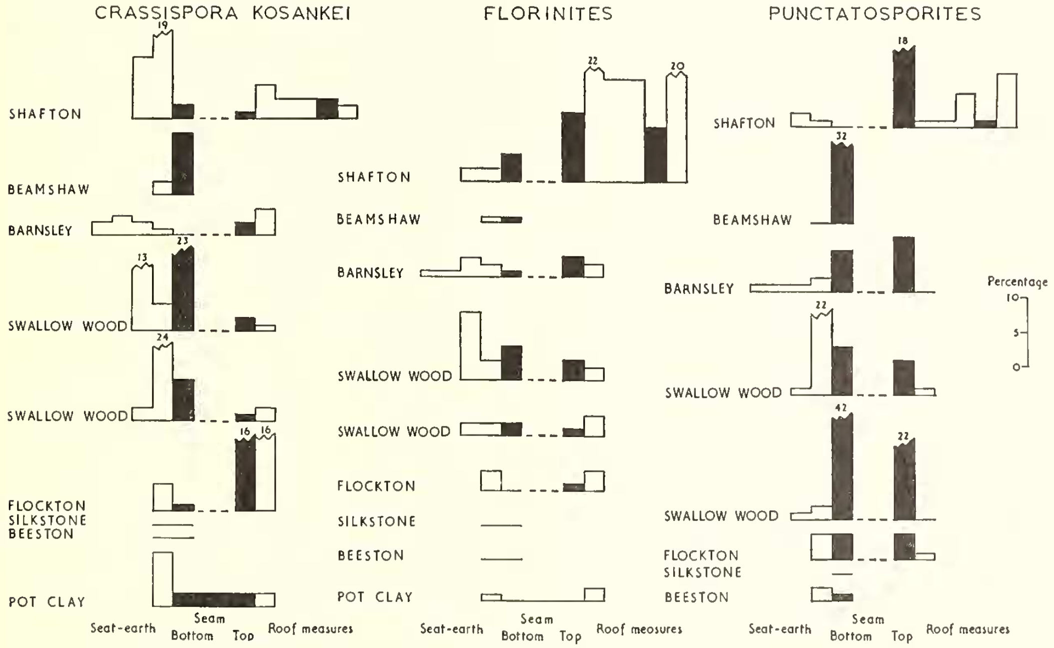
The allochthonous element probably had the following sources:

1. The vegetation of the uplands or regions marginal to the basin of deposition. Very little is known of the detailed composition of these floras.
2. The vegetation of peat bogs within the area of deposition. Except during periods of major marine transgression, peat formation was probably taking place contemporaneously with the deposition of clastic sediment.
3. Older organic or inorganic deposits which were being eroded.

It is possible that the allochthonous spores and the sediments could have been derived from different source areas. The contribution from any one source would depend on the strength and direction of wind and water currents from that quarter (Muller 1959).



TEXT-FIG. 2. Abundance of certain genera and species in seat-earths, roof measures, and associated coals of some Yorkshire seams.



TEXT-FIG. 3. Abundance of certain genera and species in seat-earths, roof measures, and associated measures of some Yorkshire seams.

During deposition of mineral sediments the contributions of the spores from the different sources is likely, therefore, to vary.

The work of Sullivan (1962) suggests that sources (2) and possibly (3) made the biggest contribution to assemblages of non-marine shales. The phase of peat bog development (Smith 1962) in the source areas would largely determine the qualitative composition of the assemblage. This perhaps explains why in the non-marine shales examined by Sullivan the proportion of the common species varied considerably. It does not account for the unusually high proportions of certain species which are normally rare constituents of the assemblages of coal seams. The possibility that some species were preferentially preserved in certain environments cannot be excluded. Any downward water movement through the seat-earths after their deposition would tend to transport the spores from the upper layers into the lower layers of the seat-earths, thereby masking the residual spore assemblage, that is, the assemblage incorporated during the early stages of deposition. The extent to which this happened cannot be determined from the available data, owing to limitations imposed by sampling, which did not extend into the lower layers of the seat-earths or the sediments below. From the study of recent soil profiles it is known that there is a downward movement of pollen grains under the influence of percolating water but that the process is very slow. The distribution curve of each species in suitable recent soil profiles assumes a characteristic form according to the length of time the pollen grains have been in the soil (Dimbleby 1957, p. 27). The greatest concentration of pollen grains is generally near the surface and this is true of the spores in seat-earths. However, it is doubtful whether such a movement would take place in permanently waterlogged soils (Dimbleby, pers. comm.).

If it is assumed that plants were growing on seat-earths before the formation of peat, although the spores provide no evidence of this, it may be inferred from the spores that the vegetation mainly comprised arborescent lycopods. Only if peat formation followed immediately on the colonization of the seat-earths by plants is it necessary to postulate that the bulk of the lycospores in their upper layers were derived from peat vegetation which had already begun to form in the neighbourhood. Very little can be inferred from the presence of rootlets in seat-earths. Their presence in some cases through a considerable thickness of sediment could have resulted from the burying of successive generations of stigmarian rootlets. On the other hand they could include the roots of rhizomes of other plants which grew downwards rather than horizontally but which were established for a relatively short period.

It is interesting to compare the occurrence of certain other spore species which constitute the seat-earth assemblages with their occurrence in coal.

Laevigatosporites Ibrahim is a genus which occurs in small numbers in the assemblages of seat-earths and bottom coals but generally becomes prominent in coal seams at a later stage in their development (Smith 1962). The occurrence of this species contrasts with that of *Densosporites sphaerotriangularis* Kosanke, which occurs consistently in small numbers in seat-earth assemblages but is not common in the assemblages of the bottom coals, although generally it becomes numerically important in the middle or upper portions of coal seams (Smith 1962). This may result from a preference of the parent plants for certain types of environment but it may indicate a different source for the spore. Kremp (1952) has suggested that Densospores of this type are an allochthonous element in coal seams although Smith (1957) does not support this view. It is, however, quite probable that a peat bog at the appropriate stage of development was the source of this spore in small numbers in the seat-earths.

Other genera such as *Crassispora* Bharadwaj, *Florinites* Schopf, Wilson, and Bentall, and *Punctatosporites* Ibrahim, which occur commonly in seat-earths, are associated in coal seams with the occurrence of allochthonous petrographic constituents (Smith 1962). These species may, therefore, sometimes occur in numbers in the bottom coals. It is probably valid to make a distinction between *Florinites*, which occurs in relatively small numbers, and the other two genera, which are more abundant in seat-earths and certain types of coal. *Florinites* may represent a wind- or water-borne element in both coals and seat-earths, since Neves (1958, 1961) found it abundantly represented in marine deposits. A marine incursion would probably eliminate the swamp-peat vegetation as a source of this genus, which was more likely derived from the vegetation growing on the higher ground (Chaloner 1958).

It is possible that *Crassispora* and *Punctatosporites* are autochthonous elements in the assemblages of seat-earths and coals but their occurrence in a certain type of peat-swamp environment, in which the allochthonous *Florinites* is deposited, is due to a preference for this environment by their parent plant. Possibly this particular peat-swamp environment shared some features in common with that of the seat-earths.

The allochthonous element of seat-earths, therefore, comprised spores from the vegetation of lowland peat swamps (*Densosporites sphaerotriangularis*) and of upland regions (*Florinites*). These spores were mainly water-borne and were deposited along with mineral sediment. As the vegetation became established on the seat-earth and peat began to accumulate the contribution from the water-borne element to the assemblage would diminish, but flood waters would introduce such spores occasionally as an element of the peat-swamp assemblage.

There is another element in seat-earth assemblages, represented by the spores described in this paper which are normally rare in assemblages from autochthonous coal seams. These species may represent plants more or less restricted to the seat-earth vegetation. Had they originated from plants growing outside the basin of deposition it is likely that they would occur in those parts of seams containing allochthonous petrographic constituents including spores (Smith 1962).

There do not appear to be any common species in coal seams which are not represented in seat-earth assemblages, although some of the less common species found in coals have not so far been recorded from the seat-earths.

The present investigation has shown no evidence for the existence on the seat-earths of a distinctive type of vegetation differing markedly in composition from that which formed the initial peat layers. It can be inferred from this that the edaphic conditions were not those of a well-drained, terrestrial soil. The evidence suggests that as peat began to accumulate the vegetation of the seat-earths persisted more or less unchanged, except for slight changes in the relative proportions of the different genera and species and for the elimination of a few species unable to survive in the more specialized environment of a peat bog or in competition with the more successful arborescent forms.

It is also unlikely that the seat-earths were covered by any depth of stagnant water for long periods except in those rare instances where cannel coal occurs now at the bases of coal seams. Maurenbrecker (1944, p. 90) records an example of such an occurrence and it is significant that in this case a seat-earth was not developed beneath the cannel.